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SOME MAGNETOMETRIC AND GRAVIMETRIC SURVEYS IN THE TRANSVAAL

BY

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PREFACE.

Various methods of geophysical prospecting have been used during the past few years by mining companies and others in the Union and under certain conditions have proved of considerable value in the search for hidden minerals. Much of this work has been of a confidential nature, and nearly all of it has been directed towards specific and definite ends.

The proved value of certain methods under certain conditions seemed to call for a more systematic investigation into the applicability of each method under varying conditions and into the relationship between problem and methods; and the Geological Survey was authorized to undertake such investigations.

The present Bulletin is to be looked upon as a preliminary statement of the results obtained in the trial of two methods under localized conditions. It still remains to be shown whether the results obtained are of general application or are limited in sphere; and experiments will continue to be conducted with that end in view.

SIDNEY H. HAUGHTON,
Director, Geological Survey.

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INTRODUCTION.

NOTE ON THE EARTH-MAGNETIC AND GRAVIMETRIC METHODS.

The theory of these methods is given in various textbooks and other publications. Without going into details of the scientific principles of the methods, the following might be of interest in connection with this report.

The earth-magnetic measurements were carried out by vertical magnetic field balances of the Lloyd-Schmidt type. These instruments measure the relative values of the vertical component of the magnetic intensity. By selecting a base station where the above value is supposed to be nil, all the observations are reduced to this base station. The latter in the present work was located on the old granite, which is only very weakly magnetic. The stations were located at suitable intervals according to each problem.

The results are given in the shape of curves obtained by plotting the position of the stations as abscissae and the corrected relative values of the vertical magnetic intensity as ordinates. Another method of graphical representation is the drawing of isogam lines by connecting points of equal vertical magnetic intensity.

The magnetic anomalies were plotted positive where the south pole of the magnet of the vertical magnetometer was attracted by the magnetic rocks, so that the positive anomalies indicate north magnetic poles in the magnetic rocks.

The gravimetric method is based on detecting minute variations in the distribution of the gravitational force. The latter, within a small space, depends on the distribution of the denser and lighter masses. The Torsion Balance re-acts upon the variations of the horizontal component of the gravity force, and therefore detects lateral variations in the distribution of denser and lighter masses. The gradient and curvature values measured by the Torsion Balance will change where the lateral distribution of the masses changes. The instrument is affected by the distribution of the masses both on the surface (hills, valleys) and underground. The former effect in the present work was carefully eliminated by detailed mapping of the terrain around every station up to a distance of 1,100 metres, and calculating the effect of the terrain and topography. This effect is subtracted from the observed values. The sub-surface effects are partly due to shallow heterogeneities of the soil, and partly to the greater masses at depth. The shallow effects can be detected through the fact that they are limited to stations in the immediate vicinity of the surface mass. These so-called local effects can be easily seen from the rapid changes of the curves. The deep effects are distributed over a larger number of the stations and show regularities in the curves. In the case of definite change in the distribution of the sub-surface masses, the gradient and curvature curves both show regular variations. It is this type of gravitational anomaly which has to be interpreted for detecting hidden geological structures. In practice, the local effects are superimposed upon the deep effects and therefore the curves of gravitational anomalies are not as smooth in practice as they are in text books. For ascertaining the reality of newly-detected anomalies, the best way is to run several parallel traverses at suitable distances apart.

The Torsion Balance can detect such geological structures as involve changes in the lateral distribution of lighter and denser masses. Faults, anticlines, domes, old river beds, unconformities, etc. can be detected at great depth if there are sufficient density differences in the rocks brought in contact through the above type of geological structure. The usual density differences found in the Witwatersrand are of the order of 0·1 to 0·2 (see Appendix).

The positions of the Torsion Balance stations are marked on the plans by small circles and numbered in the sequence of the observations. On each station the gravitational gradient is marked by an arrow, the direction of which points towards the maximum rate of change of the horizontal component of the gravitational force. The length of the arrow gives the magnitude of the gradients in a suitable scale of Eötvös units (1 Eötvös unit is 1×10^{-9} C.G.S. units). The so-called " curvature values " are also plotted on each station and represented by a straight line. The direction of the line is in the direction of the minimum curvature and its length, plotted on the same scale as the gradient, shows the magnitude of the curvature value.

The Torsion Balance data are also shown in the shape of curves along each traverse. The curve of gradients (full line) is obtained by plotting the components of the gradients in the direction of the base line at points projected at right angles to the base line from each station. According to choice, the components in one direction are plotted as positive, and in the opposite direction as negative values.

The curves of the curvature values (dotted line) were obtained by calculating the components of the curvature in the direction of each traverse. Positive values mean that the direction of the curvature is in the direction of the traverse, and negative values indicate that their direction is at right angles to the traverse.

For the sake of convenience all curves were drawn in positions shifted from the actual Torsion Balance traverses to which they belong.

By integration of the gradient values from station to station it is possible to obtain the relative values of the gravitational force and to draw lines of equal gravitational force, which are called isogam or isodynam lines. The above integration may produce considerable accumulative errors. By carrying out the integration in closed lines the error of closure can be determined and eliminated or suitably distributed. The final isogam lines are drawn from these corrected values.

APPENDIX.

DENSITIES OF ROCK SAMPLES FROM THE KARROO, TRANSVAAL, VENTERSDORP, AND WITWATERSRAND SYSTEMS.

The writers are greatly indebted to the Union Corporation, Ltd., for permitting the publication of the following data determined by C. A. Cousins and V. Baines.

AREA: Van Dyk Mine, Boksburg.

Karroo Beds.

			Mean.
Sandstone (fine to medium fine grain, O/C samples)	2·41 2·43 2·48 2·43	2·44	
Sandstone (fine grain, from BH core)............	2·19 2·21	2·20	2·31
Sandstone (medium grain, from BH core)........	2·30 2·27	2·28	
Sandstone (coarse, from BH core)...............	2·31 2·32	2·31	
Dwyka tillite (no large pebbles, BH core)........	2·38 2·39	2·39	2·49
Dwyka tillite (distinct pebbles, BH core).........	2·69 2·52	2·60	
Dolerite (from sill, shaft samples)......................		2·97 2·98	2·98

Witwatersrand Beds.

Main Bird quartzite (shaft samples, translucent grey green)	2·64 2·67 2·69 2·64 2·66	2·66
Main Bird shaly quartzite (shaft samples, opaque green fine grain)	2·76 2·74 2·76 2·77 2·79	2·76
Main Bird quartzite (BH samples)........................	2·66 2·63 2·67 2·66 2·69 2·71	2·67

		Mean.
Bird amygdaloid (no amygdales, BH cores)	2·75 2·76	2·75
Bird amygdaloid (amygdales, shaft samples)	2·78 2·81	2·79
Main reef conglomerate (slightly mineralized, shaft samples)	2·63 2·64	2·63
Main reef conglomerate (very mineralized, shaft samples)	2·75 2·76 2·71	2·74
Shale (Jeppestown, footwall Main reef, shaft samples)	2·86 2·84 2·79 2·79 2·84 2·74	2·80
Shale (as above, footwall, main reef; BH cores)	2·78 2·76 2·88 2·86 2·81	2·82
Khaki footwall shale (shaft samples)	2·72 2·67	2·70
Kimberley-Elsburg quartzite (white, O/C sample)	2·62	2·62
Kimberley-Elsburg conglomerate (O/C samples)	2·66 2·62 2·63	2·64
Kimberley-Elsburg Contact Reef (mineralized and altered by lava, O/C samples, top of series)	2·70 2·69	2·70

Transvaal System.

Black Reef Series.

Quartzite (black, O/C samples)	2·63 2·65 2·65	2·65
Conglomerate (black with white quartz pebbles, O/C samples)	2·63 2·64 2·64	2·64

Quartzites (less well consolidated fine-grained, pink, O/C samples)	2·54	
	2·59	
		2·56
Ventersdorp System.		
Amygdaloidal andesite (no amygdales)	2·76	
	2·77	
	2·77	
		2·77
Amygdaloidal andesite (amygdales well developed)	2·70	
	2·67	
	2·69	
	2·71	
		2·70

CHAPTER I.

MAGNETOMETRIC TRAVERSES ACROSS THE LOWER WITWATERSRAND SYSTEM. (PLATE II.)

Magnetometric methods of geophysical prospecting have been extensively used during the last two or three years for the purpose of locating the zone of the sub-outcrop of the Main Reef series, in areas where the Witwatersrand system is covered by a considerable thickness of younger rocks. This is done by the indirect method of tracing the various magnetic markers, which are strongly magnetic shales occurring in the Lower Witwatersrand beds.

The magnetometric traverses I and II on plate II were laid down over the broad outcrops of the Lower Witwatersrand beds which occur west of Randfontein on Witfontein No. 29, and traverses A and B are on Witpoortje No. 44, where the Jeppestown series is well developed. The Lower Witwatersrand beds consist of an alternation of shales and quartzites, and for a detailed geological description reference should be made to "The Geology of the Witwatersrand" by E. T. Mellor. The magnetometer stations were placed at intervals of 100 feet, but the station interval was reduced to as little as 10 feet where the magnetic anomalies were large. A main base station was established on the Old Granite and secondary base stations were correlated to this during the course of the survey. Temperature, base value and diurnal variation corrections have been applied to the readings at all stations, and every twentieth station was observed by both instruments, the scale value used being in the vicinity of 15 gammas.

Traverses I and II were commenced on the Old Granite to the north of the escarpment of the Orange Grove quartzites, which marks the base of the Witwatersrand system. The traverses are as nearly as possible at right angles to the strike of the Witwatersrand beds and on plate II are plotted as parallel, although the actual bearings differ by a few degrees. The readings on the granite are steady, whereas the contact of the granite and quartzite is marked in both instances by a small but definite drop in the magnetic intensity values. The outcrops of the hard, ferruginous Water Tower slates, and of the Contorted bed, are well shown on both the curves by zones of extremely large magnetic anomalies, the readings ranging from as much as $+10{,}000\gamma$ to less than $-10{,}000\gamma$.

Three further shale bands of the Hospital Hill series are marked by anomalies of a lesser degree, while the lowest shale band of the Promise Reef beds at the base of the Government Reef series is well shown on both curves as a comparatively strong anomaly. On traverse II the outcrop of the overlying Black Reef quartzites is marked by a similar drop in magnetic intensity as was observed at the commencement of the Orange Grove quartzites. Traverse I crosses well developed outcrops of West Rand or Coronation shale and the magnetic anomalies observed are of the same order of magnitude as those observed over the Water Tower slates and Contorted bed, whereas traverse II skirted a small inlier of Witwatersrand beds on Venterspost No. 27, the West Rand shales underlying a thin cover of Black Reef quartzites, the result being that anomalies observed are somewhat smaller, in the vicinity of 3,000γ, and are also consistently positive. Furthermore, the displacement of the West Rand shale anomaly in traverse II affords evidence of the faulting which exists between the two traverses, the effect of which is a considerable horizontal displacement of the position of the West Rand shale. South of the West Rand shale anomaly in traverse I are further minor anomalies. The strongest of these occurs 4,200 feet south of the centre of the West Rand shale anomaly, where the Witwatersrand beds are not exposed. This position coincides with the estimated position of the Government Reef shale and the weaker anomaly which immediately succeeds it is perhaps a repetition due to faulting. At the southern extremity of traverse I is a small anomaly which coincides with the estimated position of the Jeppestown shale anomaly.

The only feature south of the West Rand shale on traverse II is a sharp negative anomaly indicating the presence of a dyke, the magnetic effect of which may be attributed to the permanent magnetism of the dyke, to induced magnetism in the dyke, and to the fact that the dyke cuts the West Rand shale in depth.

Traverses A and B were commenced on the West Rand shales and extended southwards to the Main Reef series. The beds of the Witwatersrand system in this area not only have a steeper dip than those in traverses I and II, but the thicknesses are also considerably less. The three anomalies shown in these traverses are the West Rand shales, Government Reef shales and the base of the Jeppestown series, the Government Reef shale anomaly being comparatively weak.

The data shown in the curves may be summarised in the following table of measured thicknesses.

Table I.

Orange Grove quartzite—West Rand shales (Witfontein No. 29).

Anomaly.	Vertical distance from base of Orange Grove quartzites in feet.			Vertical distance between anomalies in feet.		
	Trav. I.	Trav. II.	Mean.	Trav. I.	Trav. II.	Mean.
Water Tower slates............	850	800	825	1,900	1,350	1,625
Contorted beds................	2,750	2,150	2,450	2,100	3,450	2,775
Lower Hospital Hill shales......	4,850	5,600	5,225	1,850	1,100	1,475
Middle Hospital Hill shales......	6,700	6,700	6,700	1,950	2,250	2,100
Upper Hospital Hill shales......	8,650	8,950	8,800	1,200	1,450	1,325
Promise beds..................	9,850	10,400	10,125	4,550	faulted	—
West Rand shales..............	14,400	faulted	—			

TABLE II.

West Rand shales—Main Reef (*Witpoortje No.* 44).

Anomaly.	Vertical Distance from Main Reef, in feet.			Vertical distance between anomalies, in feet.		
	Trav. A	Trav. B	Mean.	Trav. A	Trav. B	Mean.
West Rand shales	2,967	3,438	3,203	713	928	821
Government Reef shales	2,254	2,510	2,382	600	855	727
Jeppestown shales	1,654	1,655	1,655			

The relative positions of the traverses may be seen in the key map (Plate I), and although separated by a distance of some miles, the anomalies are seen to be remarkably consistent. The West Rand shale, giving a strong and most consistent anomaly, and occurring at a horizon near the Main Reef series, is of the greatest importance in magnetometric surveying for the purpose of determining the position of the sub-outcrop of the Main Reef series, although the Jeppestown shale anomaly, which is even nearer to the Main Reef, is extremely well developed on the far West Rand and has been extensively used as a marker in that area.

CHAPTER II.

A GRAVIMETRIC SURVEY OF THE DOORNKOP FAULT.

(PLATE III.)

The main topographical and geological feature of the area covered by this survey is a small but well-defined ridge extending in an E.-W. direction, which is due to the presence of an inlier of quartzites of the Kimberley-Elsburg series, formed by a gentle anticlinal fold of the beds of the Witwatersrand system. To the north these quartzites dip at 20° N. under a shallow covering of Ventersdorp amygdaloidal lava, while the southern limb of the anticline is faulted and thrown down to the south by the Doornkop fault, thus bringing Kimberley-Elsburg quartzites into contact with the younger beds of Ventersdorp and Transvaal systems. The position of the fault can be located at the surface at stations 38 and 44, the quartzites dipping at 12° N. being in contact with the red soil typical of dolomite areas.

During the course of the survey a number of density determinations were made, giving the following results:—

Type of Rock.	Density.		
	Max.	Min.	Mean.
Kimberley-Elsburg conglomerates	2·76	2·68	2·73
Kimberley-Elsburg quartzites	2·75	2·66	2·68
Kimberley-Elsburg quartzites (weathered)	2·62	2·57	2·60
Vein quartz	—	—	2·64
Ventersdorp amygdaloidal lava	2·89	2·75	2·79
Dolomite	2·91	2·89	2·90
Chert	2·66	2·64	2·65

The effect of normal weathering being to decrease the density of a rock, to avoid errors from this source the samples for the above determinations were collected from a depth between 10-60 feet. That the decrease in density due to weathering is appreciable is shown by the abnormally low density value of 2·60 for quartzites collected from an outcrop in the vicinity of the fault. Further, as the degree of mineralisation has a measurable effect upon the density of the quartzites and conglomerates, the maximum value in both cases was obtained from measurements of specimens which showed distinct signs of mineralization. In the case of the determinations of the density of the amygdaloidal lava, the highest values were invariably found with specimens with a fine-grained matrix and few amygdales, whereas the type with large, well-developed amygdales gave an appreciably lower density value.

The Torsion Balance traverse (Plate III) is in an approximately N.-S. direction, and its position relative to the geological features of the West Rand may be seen in the key map (Plate I). The traverse was commenced on the dolomite in the south, the station interval chosen being 100 metres, although this was reduced where necessary, usually to 50 metres. Over the area where gravitational anomalies due to the presence of the Doornkop fault were located, two short parallel traverses, A and B, were laid down, in order both to check the results obtained from the main traverse, and to give additional information. The observed readings at all stations have been corrected for terrain effects up to a distance of 100 metres, while topographical corrections up to distances of 1,100 metres have also been applied, these being calculated from a 1 metre-interval contour map of the area which was prepared for the purpose.

The gravity values over the Dolomite between stations 52 and 4 are small, the gradients having a marked easterly component, probably due to the thickening of the lava in this direction. The area between station 4 and station 11 is conspicuous as a zone of strong gravitational anomalies, the gradients at some stations having a northerly component of as much as 100 Eötvös units. This northerly direction of the gravity gradients is exactly opposite to the results expected from the density determinations, as from them it would seem that the gradients should point south, the density of dolomite and lava being 0·2 higher than that of quartzite. The observed direction of the gradient is due to the extreme thickness of soil overlying the Dolomite in this area, thus giving, in effect, a quartzite-soil contact, the density of the soil being almost 1·0 less than that of the quartzite. This thickness of soil is not exceptional, as the weathering of dolomite* areas gives rise to a deep-reddish residual soil with blocks of insoluble chert, the thickness of which may rise to 100 feet, while at the main pumping station at Zuurbekom No. 9, about five miles south of the Doornkop fault, no less than 466 feet of soil and chert rubble were penetrated before striking solid dolomite.

From the gradient values, the fault is indicated at stations 38, 37, 7 and 43, while from a further consideration of the curvature values the exact position of the fault may be plotted as on Plate III. The direction of the curvature is in a N.-S. direction south of the fault, while the sudden change to an E.-W. direction of minimum curvature delineates the fault plane. The gradient and H.D.T. curves are plotted as N.-S. sections, the main section being obtained from the consideration of all the observed values, while sections A and B only take into account the stations in the immediate vicinity of traverses A and B. The three sections all indicate an approximately vertical fault, the main section and section B giving evidence of a slight hade to the south, while a vertical contact at station 38 is indicated in section A by the following features:—

(1) The gradient and H.D.T. curves are symmetrical.

(2) The point of maximum gradient is in the same horizontal position as the change of sign of the curvature values, both positions being at station 38.

(3) The maximum curvature value coincides with the position of one-half the maximum gradient value.

Furthermore, the very fact that the gradients point northwards shows that there cannot be large masses of dolomite and amygdaloidal lava immediately south of the fault plane, and therefore the throw of the fault is small.

The continuation of the traverse northwards extended over the edge of a basin of overlying Ventersdorp amygdaloidal lava, as is shown on Plate III. This contact of quartzite and lava dips at 21° N. and is shown up by the large curvature values at stations 14, 17, and 18, while evidence of the commencement and gradual thickening of the lava to the north is afforded by the steadily increasing values of the gradient curve between stations 14 and 21.

In conclusion it may be stated that the Doornkop fault was well defined as a zone of strong gravitational anomalies and that it could be delineated by use of the Torsion Balance. The results indicate a fault which has a small southerly hade and the throw probably is not more than 500-600 feet.

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* The Geology of the Country surrounding Johannesburg. Chap X. A. L. du Toit.

CHAPTER III.

GRAVIMETRIC SURVEY OF THE WITPOORTJE FAULT AND LOWER WITWATERSRAND BEDS ON WITPOORTJE No. 44. (Plate IV.)

A gravitational survey was carried out on the farm Witpoortje No. 44 to determine whether the Witpoortje fault could be located by the use of the Torsion Balance. In addition, two traverses were run across beds of the Government Reef series south of the fault to investigate the gravitational anomalies due to the alternating bands of quartzite and shales. From the key map of the traverses it will be seen the Witpoortje fault, striking E.-W., passes through the northern part of the area investigated. To the north of the fault lie Upper Witwatersrand beds, while to the south is the block of Lower Witwatersrand beds, which cause the gap in the Main Reef series known as the Witpoortje break. These Lower Witwatersrand beds extend southwards to the Roodepoort fault, south of which the upper beds of the Witwatersrand system re-appear. The exact position of the Witpoortje fault is not clear, owing to the lack of outcrops of the alternating shales and quartzites south of the fault. The only definite contact observed was that of the Government Reef with underlying shales. In the east of the area the position of the fault is further obscured due to the beds both north and south of the fault being shales, while there is also evidence of minor faulting in that neighbourhood.

In the west the upper Witwatersrand beds, represented by Kimberley reefs and shales, are cut off by the fault, the position of these shales being very indefinite, although the reefs occur as well defined outcrops in the quartzite, striking in a south to south-east direction.

The Torsion Balance stations were laid down at intervals of either 50 metres or 75 metres over the area of the Witpoortje fault, while 100 metre stations were occupied on the traverses across the Government Reef series. Terrain corrections up to 100 metres and topographical corrections for distances up to 1,100 metres were applied to the observed values at all stations, the latter being calculated from a 1 metre-interval contour map of the area, which was prepared for the purpose.

In the vicinity of the Witpoortje fault the gradients invariably have a strong southerly component and the position of the fault is marked by the position of the maximum gradient values, occurring at stations 1C, 6, and 7A. The curves for traverse A indicate the position of the fault at station 7A by the gradient curve showing a definite maximum and the H.D.T. curve showing a reversal of sign. Traverses 1, B and C are parallel to traverse A, and although traverses I and C show a remarkable similarity to each other, the curves show that the conditions are very disturbed and do not give sufficient corroborative evidence to uphold any assumptions derived from the interpretation of the results of traverse A. Traverse E, also, does not give any clear indication of the fault, as the maximum gradient value at station 32E is probably caused by the surface effect of a contact between quartzite and shale, while the H.D.T. curve is too irregular to allow of any definite interpretation.

Traverse D, across shales and quartzites of the Government Reef series, gives strong indications of all the contacts between quartzite and shale, but that these results are due to surface effects is well shown at the Government Reef—shale contact at station 20D. Here there is a large gradient anomaly, the gradient pointing towards the Government Reef and away from the shale footwall. This is due to the fact that, although the shales have a slightly greater density than the quartzites, they weather much more readily, causing the quartzites to stand out as hard outcrops in contact with the lighter weathered shale and derived soil. Traverse E, parallel to traverse D, shows up the Government Reef shale contact in a similar manner, but the curve is more irregular and does not give such clear indication of the other contacts.

The results of this survey show that although the difference in density between quartzites and shales may be great enough to give good results at a well-defined and unweathered contact, a gravitational survey over outcropping shales and quartzites of the Witwatersrand system is liable to show anomalies arising from the surface effects due to differential weathering. Under favourable conditions the latter effect can be used for the mapping of well defined and geologically identified contacts of shale with quartzite under a thin cover of soil.

The Witjoortje fault does not give rise to large gravitational anomalies where quartzites and shales of very similar character are on both sides of the fault. The consistent southerly direction of the gradients in the vicinity of the fault is due to the block of the lower Witwatersrand beds, with its numerous shale bands, being of a greater average density than the beds of the upper Witwatersrand series.

A fault of this nature can be more accurately delineated by a Torsion Balance survey when the Witwatersrand beds underlie a cover of younger beds of a different density which are also involved in the faulting.

CHAPTER IV.

THE DETERMINATION OF THE HADE OF THE WITPOORTJE FAULT BY A MAGNETOMETRIC SURVEY.

(Plate V.)

The relative position of the four magnetometric traverses across the Witpoortje fault on Rietvlei No. 113 are shown in diagram I, Plate V. To the north of the fault, in this area, are outcrops of quartzites and conglomerates of the Kimberley-Elsburg series which dip at 20° E., occasionally overlain by a thin covering of Black Reef quartzites, while south of the fault are quartzites of the Government Reef series and extensive outcrop of Jeppestown shales, dipping in a south-easterly direction at 15°.

No magnetic anomaly is present at the surface position of the fault, which is marked on all the traverses, but the points A are the positions of the maximum values of an anomaly the characteristics of which show that it results from a deep-seated magnetic disturbance, and may be attributed to the West Rand shales, which in this area are cut off by the fault plane at a depth of approximately 4,400 feet. In traverse III this position A happens to coincide with the position of a dyke, which has in other areas been traced in the same relative position to the Witpoortje fault. Further south the traverses show the anomaly at the base of the Jeppestown series, which in this area is abnormally broad, a fact due, no doubt, to extensive strike faulting, evidence of which was seen.

Diagram 3 shows the method of estimation of the hade of the Witpoortje fault in this area. Thicknesses are estimated from measurements of Witwatersrand beds on Witfontein No. 29, Witpoortje No. 44, south of the Witpoortje fault (Witpoortje gap), and Witpoortje No. 44, north of the fault.

A variation of 1,500 feet in the estimated depth of the West Rand shale was found to give an error of less than 3° in the calculated dip of the fault, the calculations giving the following results:—

Traverse.	Dip of Fault.		
	Minimum.	Maximum.	Probable.
I............................	60°	81°–30′	78°–30′
II...........................	70°	84°–15′	82°-15′
III..........................	64°	83°-0′	80°
IV...........................	81°–45′	88°	86°-45′

The direction of dip was in all cases towards the younger beds to the south-east, and a mean value for the dip is 81°-53′.

CHAPTER V.

TORSION BALANCE SURVEY FOR LOCATING NICKEL ORE PIPES ON VLAKFONTEIN No. 902. (Plate VI.)

Introduction.

A survey employing the Eötvös Gravitational Variometer or Torsion Balance was undertaken on Vlakfontein No. 902 about 38 miles north-west of Rustenburg, Transvaal, to determine the applicability of this method of geophysical surveying for locating and delineating nickel ore pipes as revealed on the surface by outcrops of gossan. The topography of the area investigated lends itself admirably to gravimetric work, as it is generally of a very flat or else gently sloping nature. In addition the hills of the Pilansberg massif are sufficiently distant to have little or no effect on the Torsion Balance.

Most of the area investigated is overlain by " black turf " soil which in wet weather becomes completely impassable for wheeled traffic and, as a consequence, no field work is possible while it is in that state. On drying, the soil developes contraction cracks and, on being cleared and levelled to receive the balance, breaks up into irregular lumps.

Geology of the Area.

The geology of the nickel-ore occurrences has been fully described in Wagner's Memoir 21 on " Magmatic Nickel Deposits of the Bushveld Complex in the Rustenburg District, Transvaal " and also in " The Nickel-Copper Occurrences in the Bushveld Igneous Complex west of the Pilansbergen ", Geological Series, Bulletin No. 5, by C. M. Schwellnus, B.Sc.

The following short description is taken from the latter paper. The nickel pipes or gossan outcrops as they appear on the surface are confined to the marginal basic rocks of the norite zone of the Bushveld Complex. This zone occupies a broad stretch just west of of the Pilansbergen around which it sweeps with a strike roughly parallel to the outcrop of the outer fringe of the Pilansberg eruptives.

The nickel pipes chosen for gravimetric investigation were those on Vlakfontein No. 902. This cluster of pipes is the most southerly as yet exposed and lies about four miles north of the contact with the altered Magaliesberg shales, and to the south-west of the Pilansberg intrusive.

From the detailed geological map of this area in Wagner's Memoir 21 it is seen that the country rock around this cluster of pipes is essentially bronzitite with numerous lenses of serpentinized harzburgite and anorthositic norite.

These pipes were chosen as they have been developed to a depth in some cases of 300 feet to 400 feet and data regarding their dimensions is thus available.

Description of Pipes with Regard to Torsion Balance Prospecting.

The conditions necessary for a successful survey of the pipes are as follows:—

(1) A difference in specific gravity between the ore body and the country rock.

(2) Reasonable size of the ore body.

(3) Suitable topography.

The first condition is well fulfilled as the ore body, consisting almost completely of pyrrhotite, pentlandite, and chalcopyrite, has an average sp. gr. of 4·62. Comparing this value with that of the predominant country rock bronzitite, i.e. 3·34, it will be seen that a large difference in sp. gr. exists. The serpentinized harzburgite and anorthositic norite have the average sp. grs. 3·01 and 2·92 respectively. When it is realised that successful results have been obtained with a specific gravity difference of 0·2 it is evident that the density difference here is ample.

To a certain extent the effect due to the large gravity difference of ore and country rock is limited by the small diameters of the pipes, which rarely exceed 50 feet.

A further point which has to be considered is that the nickel ore does not persist to the surface: there is a zone of weathering reaching from the surface down to as much as 100 feet.

Thus the top of the pipe is filled with opalescent gossan, varying from an extremely light friable material to slightly weathered nickel ore. The range of sp. gr. is naturally a very large one till the fresh ore is reached. As a result of this weathering, near the surface of the pipe the country rock is of greater sp. gr. than the pipe material and thus further complicates the gravitational conditions around the pipe.

Procedure.

As it was not known what effect the nickel pipes would have on the Torsion Balance, it was decided to survey first a known ore body and then an unproved gossan outcrop. By comparing the two results obtained, it might then be possible to obtain some idea as to the possibility of nickel ore underlying the unproved gossan and, if so, in what quantities it might be expected to occur. Unfortunately all the pipes about which data was available had been opened up and were surrounded by dumps of waste rock thrown out during development. This naturally precluded the possibility of using the Torsion Balance directly over the ore body. However one of the larger pipes was chosen as it fortunately had the smallest dumps surrounding it: this pipe was the most southerly proved pipe of the cluster, and is in future referred to as the Rock Shaft.

Rock Shaft Results.

A series of Torsion Balance readings were obtained around this ore body at an average distance of 60 metres from the centre of the pipe, and the gradient and H.D.T. computed in each case. It was thought however that the stations were too distant from the pipe, and a second ring of stations were read nearer in, avoiding as far as possible the dumps of waste rock. Altogether 20 stations were observed around the Rock Shaft. The resulting gradients and curvatures were plotted, as shown on Diagram I on Plate VI.

On Diagram I the Torsion Balance stations are plotted showing their position with regard to the pipe whose dimensions at the 80-feet and 115-feet levels are represented.

At the 80 feet level the pipe is of elliptical shape having a maximum diameter of about 50 feet, while at 115 feet the cross-section has become almost circular with a diameter of about 33 feet. The ore body at depths greater than 115 feet is unfortunately not yet exposed. From the diagram it is seen that large values for the gradients are obtained; on St. 7 the gradient was 170 Eötvös units, while in several other instances gradients almost as large are to be observed. The most notable feature of this survey is, however, the strong south-easterly tendency of the gradients. The regularity of this tendency points towards the presence of a regional anomaly of a south-east trend. At first sight it would not appear that the ore body has any effect on the gradients and curvature. Closer inspection shows that in the north-west, where any effect due to the ore body would be increased by the south-east regional anomaly, the gradients are larger than those in the south-east where the ore body effect is opposing the regional anomaly. To eliminate the regional effect, the mean value of all the gradients was calculated and subtracted from the original gradients observed on each station. The curvatures were treated in a like manner and the corrected results plotted as shown in Diagram II. In Diagram II the gradients point towards the ore body in almost every instance. The curvatures also are definitely affected by the ore body as they tend to resolve themselves radially around the ore body. It will also be observed that the size of the gradients of the outer stations is generally larger than that of the inner stations. This is a normal condition. The effect of the gossan is small as proved by the fact that the gradients point towards the centre of the pipe and not away from it as they would if due to the light mass of the gossan. The latter effect could be expected when actually observing Torsion Balance stations right on the gossan.

Isogam Plan of Rock Shaft.

In Diagram III the gravity anomalies are represented by means of lines of equal gravitational force or isogams. These lines connect points of equal gravity around the ore body and are constructed from the gravity gradients on Diagram II. The isogam interval in this case is 2×10^{-4} C.G.S. units giving a difference in gravity of 16×10^{-4} C.G.S. units between the outermost and the innermost isogams.

Naturally the ore body which has given rise to this variation of gravity should fall within the innermost isogam. This affords a means of determining the position of the ore body were it unknown.

From the isogam plan it is observed that the isogams do not follow closely the shape of the pipe as proved to the 115 feet level but tend to extend in a south-easterly direction. According to the interpretation of the plan this would indicate an extension of the ore body to the south-east, or else a dip of the pipe in that direction. A more probable explanation is to be found in the regional correction applied, and also in the presence of the dumps of waste rock around the pipe. As the regional correction was computed from only 20 stations it may be not quite exact. Thus if the regional effect were greater than calculated, the isogams would conform more to the shape of the pipe.

Interpretation of the H.D.T. Gradient and Gravity Curves of the Rock Shaft.

The H.D.T. and gradient curves in Diagram IV are those drawn along the section lines in Diagram II i.e. N.-S. and N.W.-S.E. The gravity curve is computed from the similar section of the isogam plan i.e. Diagram III.

It must be noted here that in the following interpretation, when a station is referred to by number, it is not its position on Diagram II that is indicated, but the projection at 90° of that station on to the section line.

N.-S. Section.

The gradient and gravity curves over this section denote the centre of the pipe about midway between stations 14 and 15. The H.D.T. curve denotes a body of a diameter of approximately 60 feet bounded on the north by station 14 and on the south by station 15.

N.W.-S.E. Section

Over this section the curves were not very regular, more especially that of the H.D.T. From the gradient and gravity curves the centre of the body would appear to be at station 17. No reliable information however can be obtained from the H.D.T. curve regarding the diameter of the body.

Where the gradient curves are very regular their shape can be utilized to find the dimensions of the body but in the above sections they are too irregular for that purpose.

From the gravity and gradient curves the centre of the pipe is given at the intersection of the section lines: this calculated point agrees closely with the results obtained by development. The N.-S. diameter as calculated agrees fairly well with the known value.

As the presence of dumps around the pipe has a far greater effect on the curvature values, and thus on the H.D.T. curves, than on the gradients, any calculations based on the former are more liable to error.

Old Shaft Results.

As a consequence of the success met with in the case of the known pipe a similar survey was carried out over an unproved gossan outcrop about a mile to the north-west of the Rock Shaft. This gossan has been named the Old Shaft since a certain amount of exploratory work has been carried out many years before but had not succeeded in locating any nickel ore.

A shaft had been sunk on the gossan itself but apparently drove through the gossan which passed out of the shaft in a north-westerly direction. From the shaft, driving was carried out to the south-east again with negative results.

Diagram V.

First a ring of stations Nos. 1-8, was observed around the gossan at an average distance of 50 metres from its centre. From the results of stations 1 and 2 it was decided to investigate further the area between them, and stations 9, 10 and 11 were read giving the results shown. From these the presence of a regional anomaly was suspected and stations 12 and 13 were observed well away from any effect of the gossan, bearing out this contention.

A further number of stations was observed in the neighbourhood of stations 1 and 2 to elucidate the anomaly in that area, with the result shown on Diagram V.

From the diagram it will be seen there is a definite gravimetric anomaly to the north-west of the gossan. To the west of that area the gradients are very large and have a south-easterly tendency, while to the east the gradients change from a south-easterly direction on stations 7, 8, and 20 to a south-westerly one on stations 19, 9, and 17. In addition the stations nearer the gossan Nos. 20 and 21, are directed away from the gossan.

Diagram VI.

This plan shows the gravitational anomalies around the Old Shaft after the regional correction had been applied. This regional correction was determined in the same manner as in the case of the Rock Shaft. The corrected values show up more clearly the area to the north-west of the gossan. From this plan the presence of a heavy mass in the area encircled by stations 14, 15, 1, 18, and 2 is evident, the gradients tending to point inwards from all the surrounding stations. Stations 20, 21, and 22 have now a north-westerly direction while those further out are greatly decreased in size.

Isogam Plan of Old Shaft.

The Isogam plan on Diagram VII was drawn to include only the north-west area of the survey as it was the most important. The interval between isogams is the same as for the Rock Shaft, i.e. 2×10^{-4} C.G.S. units. From the plan the region of maximum gravity anomaly lies between stations 15 and 18, while from that area to station 19 there is a rapid drop in gravity values.

In this area of maximum gravity anomaly between stations 15 and 18, we should therefore expect the highest point of the body. or in the case of a pipe, its centre. From the shape of the isogams the body or pipe should be of an elliptical form with its major axis running approximately north-south or else be a circular pipe dipping in a northerly direction.

Interpretation of H.D T. Gradient and Gravity Curves. Diagram VIII.

The H.D.T. and gradient curves were drawn along the section lines on Diagram VI i.e. N.-S., E.-W., and N.W.-S.E., while the gravity curves were drawn along the sections shown on Diagram VII.

The N.-S. Section.

From the gradient and gravity curves over this section the centre of the pipe is given as being 10 feet north of Station 19, i.e. lying on an E.-W. line 10 feet north of station 19, while the H.D.T. curve, which is very well defined, gives the N.-S. thickness of the pipe as 25 feet.

The E.-W. Section.

The centre of the pipe is shown to be on a N.-S. line three metres west of station 15 by both the H.D.T. and gradient curves although the gravity curve depicts it more to the east. From the H.D.T. curve the diameter is again given as 25 feet.

The N.W.-S.E. Section.

Here again the gradient and H.D.T. curves coincide in a better manner than the gravity and H.D.T.; so these will be utilized for interpretation. From the gradient curve the centre of the body lies on a line through station 23 at 90° to the section while the diameter of the pipe is given as approximately 25 feet.

From the three sections we obtain three loci of the centre of the body. Where these intersect, therefore, should be the actual centre. A small triangle of error appears, however, the centre of which is taken as the centre of the body, and is marked C on Diagram VI. The diameters calculated are consistent and give a value of 25 feet.

As the only rock heavier than the country rock in this neighbourhood is nickel ore, and the body producing the anomaly is of a heavier nature than its surroundings, it can therefore be assumed that the body is a pipe of nickel ore of diameter approximately 25 feet underlying the position marked on Diagram VI.

Conclusions.

From the results of these two surveys it would appear that the Torsion Balance can be successfully applied to the location and delineation of nickel ore pipes notwithstanding their relatively small diameters. It is necessary however to have closely spaced stations and on this account the survey of a large area for locating individual pipes is a costly undertaking. In cases of unproved gossans, however, the gravimetric method is of use in determining the presence of underlying ore and in what quantities it may be expected.

Regional Anomaly.

Diagram IX shows the regional anomalies at the Old Shaft and Rock Shaft as determined from the survey around those areas.

Stations A1, A2, B1, B2, C1, C2, are six stations observed for the purpose of determining whether this regional anomaly persisted in other localities.

A regional anomaly, as the name implies, is one due to some large geological structure underlying the area surveyed, or lying some distance off. Any local sub-surface effect is therefore influenced by it and correction is necessary, as in this case.

From the geological map of the Pilansberg it is seen that the area under investigation lies approximately four miles north of the contact of the norite with the Magaliesberg shales. The base of the norite dips towards the north-east at about 15° and is underlain by the shales whose specific gravity is much less than that of the norite. Any regional anomaly at Vlakfontein therefore should be northerly, due to the larger mass of norite and the Pilansberg intrusive in that direction. As stated, the area surveyed is composed of the most southerly pipes as yet opened up. The anomaly at the Old Shaft points towards the cluster of pipes and might be supposed to be due to that cause, but the rock shaft is the most southerly pipe and hence if this " regional " anomaly is due to the cluster, it should here be towards the north.

The six stations show that the south-easterly regional anomalies at the Old Shaft and Rock Shaft do not persist for any great distance. At stations B1, and B2, about one mile east of the Rock Shaft the gradients now point to the north while at A1 and A2 they point to the south. At C1 and C2 there is evidently a disturbing local effect at one or the other of the stations and no definite average anomaly is obtainable.

This survey however dealt only with individual pipes and not sufficient stations were read to advance any theory as to the body producing this gravitational effect. A more detailed survey might reveal valuable information especially in view of the search for the possible parent ore-body from which the nickel pipes may be derived.

CHAPTER VI.

A MAGNETOMETRIC SURVEY OF A GOSSAN ON VOGELSTRUISNEK No. 602. (PLATE VII.)

A prominent feature of the area on Vlakfontein No. 902 surveyed with the Torsion Balance was the presence of numerous lenses of magnetic serpentinized harzburgite. These lenses would undoubtedly interfere with any magnetometric survey in that area. It was therefore decided to conduct the earth-magnetic survey over a gossan in an area free from these disturbing effects. A suitable gossan was found to occur in the pyroxenite near a mass of quartzite float on Vogelstruisnek No. 602.

Four traverses, each 200 feet long, were laid down over the gossan, intersecting each other at their centre points which were over the centre of the gossan. On these traverses AA1, BB1, CC1 and DD1 the station interval was taken as 10 feet and 5 feet over the gossan outcrop with the results shown on Diagram X.

The Salient Features of the Four Curves are:—

1. The large negative values over the gossan.
2. The definite rise in the value of the magnetic intensity over the centre of the gossan.
3. The small rise in the curve near the edge of the gossan outcrop.

The average anomaly over the gossan is 1250γ and could be easily recognised even in a fairly disturbed area. As no magnetometric work has been carried out over a known pipe it is not possible to say which of the above three features delineate the boundaries of the pipe.

From the magnetic intensities along the traverses an isogam plan was prepared to show points of equal magnetic intensity over the gossan. This plan shows up two areas of low values of the magnetic intensity namely $-2{,}000\gamma$ and $-1{,}500\gamma$. In addition it can be deduced from the plan that the pipe is of an elliptical form with its major axis along BB1.

Conclusions.

It is evident that in areas free of magnetite-bearing country rock nickel-ore pipes can be located by means of magnetic methods of prospecting. For such work, however, stations should be placed at distances not exceeding twenty feet, to obviate the possibility of missing the pipes.

CHAPTER VII.

MAGNETOMETRIC SURVEY OF THE CHROMITITE SEAMS ON GROENFONTEIN No. 302. (Plate VIII.)

A description of the chromitite seams on Groenfontein No. 302 is given in "The Nickel-Copper Occurrences in the Bushveld Igneous Complex" by C. M. Schwellnus, B.Sc., the following description being taken from that source.

On the farm Groenfontein No. 302 S. A. Minerals Ltd. have opened up a deposit of chromitite in the form of three seams striking in a N.W.-S.E. direction. These vary in thickness, the lowest being about three feet thick while the two upper seams are much thinner. The dip is 30°-40° in a south-westerly direction while below the uppermost seam a thin hortonolite dunite lens occurs.

As hand specimens of the ore proved to be slightly magnetic it was decided to test whether the seams could be located using the magnetometers. In addition, as the uppermost seam was underlain by a seam of chromiferous titaniferous magnetite it was thought that this might prove a valuable marker.

Two traverses 200 feet apart were laid down over the three chromitite seams, with a station interval of 40 feet which was reduced to 20 feet and even 10 feet over the outcrops of the ore. The results of these traverses were plotted as shown on Plate VIII.

The only seam which gave any recognisable anomaly was the middle one. This is best seen on traverse I where an anomaly of 1,500γ was recorded between stations 0 and 2. The chromiferous titaniferous magnetite seam unfortunately gave little or no anomaly.

From the form of the curve between the seams the pyroxenite appears to be greatly disturbed, probably due to the proximity of the hortonolite dunite pipe; this naturally masks any small anomaly which might arise from the chromitite. It would therefore appear that, if the chromitite seams are to be traced by magnetic methods, it would only be possible in areas where the magnetic intensity values over the country rock were normal or constant.

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